An Initial Assessment of Microcystin in Raw and Treated Municipal Drinking Water Derived from Eutrophic Surface Waters in Alberta

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September 2002

Pub. No: T672
ISBN No. 0-7785-2417-5 (Printed Edition)
ISBN No. 0-7785-2419-1 (On-line Edition)
Web Site: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

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FOREWORD

Nutrient-rich lakes and reservoirs in Alberta commonly experience blooms of cyanobacteria (formerly called blue-green algae) during warm weather in summer and early fall. Several bloom-forming species can develop toxic strains. The toxins may be classified in two groups according to their effect on the liver (hepatotoxins) or the nervous system (neurotoxins). The hepatotoxin "microcystin" has received much attention world-wide because of its prevalence. While neurotoxin-producing blooms have been documented in Alberta, blooms that produce microcystin appear more common. Both types of toxins have resulted in the deaths of domestic animals, waterfowl and pets.

The World Health Organization (WHO) has expressed world-wide concern regarding the human health effects attributable to cyanobacteria and particularly so for microcystin which has a widespread distribution. Health Canada has recently adopted a drinking water guideline of 1.5 µg total microcystin/L.

Numerous communities in Alberta rely on treated water from eutrophic sources, but little information was available regarding the level of compliance of treated water with the Health Canada drinking water guideline for microcystin.

This scoping level study was undertaken to determine the prevalence of microcystin in treated and untreated municipal water sources and to assess the adequacy of current water treatment in reducing toxin levels.

This research project supports the "Water Issues" in the Departmental Business plan, particularly with respect to leadership and assurance. It is a direct contribution to the Drinking Water Strategy. The results provide information on the safety of the drinking water supply and draw the attention to the ongoing need for data on cyanotoxin in drinking water reservoirs, the need to improve the management of the reservoirs and their watersheds so as to reduce cyanotoxin blooms, and the need for research into improved and cost-effective treatment technology such as the ongoing work carried out at the Alberta Research Council, Vegreville, on fluidized bed biofilters.

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SUMMARY

In Alberta, many smaller communities utilize eutrophic lakes and reservoirs as their primary sources of raw water. These waterbodies are usually dominated by cyanobacteria (often referred to as blue-green algae) during summer and autumn.

International toxicological research conducted over the past several decades has revealed that certain cyanobacterial species are capable of producing potent toxins, which can be released into the water as cells senesce. These toxins are classified into two categories, based on their respective modes of action: neurotoxins, which affect the nervous system; and hepatotoxins, which affect the liver.

Microcystin, a widespread hepatotoxin, has been the topic of recent research in Alberta and it is suspected that certain communities may be exposed to this toxin because elevated levels have been measured in their raw water supplies. However, the total extent of microcystin in Alberta's raw drinking water sources remains largely undetermined. Furthermore, it is unclear whether traditional drinking water treatment practices effectively remove microcystin.

The objectives of this study were:

1. To assess the prevalence of microcystin in selected municipal raw water sources;
2. To determine if current water treatment practices adequately remove the toxin; and
3. To determine the efficacy of an experimental bio-filtration process for the removal of microcystin.

Eighteen municipalities and their raw water sources were selected for this study, based on historical data describing the incidence of cyanobacterial hepatotoxins in Alberta. The study was conducted over a 10-week period (mid August – mid October 2001) and involved the collection of both raw (surface) and treated water samples. The concentration of "total microcystin" was determined in these samples via the colorimetric protein phosphatase inhibition assay and expressed as "microcystin LR (MCLR) equivalents per litre".

Microcystin was detected in the majority (67%) of raw water samples collected during the study. Toxin concentrations were low (i.e., up to 0.5 µg MCLR eq./L) in ten of the eighteen raw water sources. However, moderate concentrations (i.e., 0.5 to 14.8 µg MCLR eq./L) were detected in seven other source waters. Only one community's source water contained no detectable microcystin throughout the study.

Microcystin appeared less often and at lower concentrations in treated water (i.e., detected in only 10% of samples), suggesting that conventional water treatment practices can remove some toxin from contaminated source waters. Concentrations in all samples complied with the Health Canada Guideline for drinking water protection.

It is recommended that sampling be conducted on a wider range of rural communities to fully evaluate the occurrence of microcystin in municipal surface water supplies.

103-01882/

ACKNOWLEDGEMENTS

This study was funded by the Water Research Users Group (WRUG), Alberta Environment.

The Towns of Swan Hills, Strathmore, Gleichen, Picture Butte, Taber, Viking, St. Paul, and Bonnyville, the Cities of Wetaskiwin and Camrose, and the Villages of Rockyford, Carmangay, Lomond, Mirror, Hay Lakes, Holden, Vilna and Boyle participated in the study by collecting or facilitating the collection of water samples from their raw surface water source and their finished drinking water. Their cooperation is gratefully acknowledged.

The study was designed and executed by Dr. Ron Zurawell (HydroQual Laboratories Ltd., Calgary).

Dave Trew, Karu Chinniah, and Anne-Marie Anderson (AENV) had technical input in the design of the study and in the preparation of the report.

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1.0 INTRODUCTION

Productive (eutrophic) lakes and reservoirs in Alberta often experience severe blooms of cyanobacteria during the warm, open water season (July – September). It is well recognized that bloom-forming species and strains of cyanobacteria, commonly of the genera *Microcystis*, *Anabaena*, *Oscillatoria* and *Nostoc*, can produce potent liver toxins termed microcystins. Microcystins are endotoxins (intracellular) and hence, predominantly exist within cyanobacterial cells. Passive release of toxin into their environment occurs naturally with senescence (cell aging) and often results in relatively low concentrations of dissolved (extracellular) microcystins. During collapse of intensive cyanobacterial blooms, however, concentrations of extracellular microcystins can become elevated.

Health Canada recently proposed a drinking water guideline for microcystin. The maximum acceptable concentration is 1.5 µg/L, which pertains to the total of both intracellular (cell bound) and extracellular (cell free) toxin fractions. The guideline was derived in consideration of daily consumption over one year (Health Canada, 1998). Compliance assessment with this guideline offers a basis to evaluate the chronic risk to humans consuming treated water from eutrophic reservoirs.

At sublethal levels, microcystins can cause intestinal and liver dysfunction in animals as well as promote liver tumor growth. Higher doses can cause severe liver damage and death via intrahepatic hemorrhage and hypovolumic shock. Consequently, microcystins have been implicated worldwide in a number of poisonings of domestic livestock (e.g., cattle, pigs and sheep), pets (e.g., dogs), wildlife (e.g., deer, ducks and fish) and humans. The primary route of hepatotoxin exposure to animals is through the ingestion of toxin-producing cyanobacteria as a consequence of consuming water from lakes and reservoirs experiencing cyanobacterial blooms. While humans undoubtedly avoid consuming bloom material, the accidental intake of water during recreational activities (e.g., swimming, canoeing and water-skiing) is recognized as the principal avenue for the direct ingestion of toxin-containing cyanobacteria cells.

Of more concern, however, is the periodic ingestion of drinking water contaminated with dissolved microcystins as a result of insufficient or ineffective drinking water treatment practices. This may be the case for smaller municipalities or rural communities that utilize traditional treatment processes involving flocculation (with ferric chloride or aluminum sulphate), sedimentation, sand filtration and chlorination. Reportedly, such methods remove up to 30% of the initial dissolved microcystin concentration (Himberg et al., 1989). In this respect, microcystins have been linked, epidemiologically, to an increased frequency of primary liver cancer in several rural regions in China (Ueno et al., 1996). Considering that numerous communities in Alberta also rely on treated water obtained from eutrophic sources, the potential for serious consequences with respect to the health and wellness of the rural population may exist.

The use of some chemical oxidants in conventional treatment processes (e.g., chlorine, ferric chloride and potassium permanganate) may actually increase microcystin concentrations in finished water by causing lysis of the cyanobacterial cells within the influent water (Lam et al., 1995).

Chemical pretreatment of bloom-prone source waters with algicides can also elevate extracellular microcystin concentrations significantly. Laboratory batch treatment of bloom material containing *Microcystis aeruginosa* with 0.64 mg copper sulphate/L induced cell lysis and subsequent release of toxin (Kenefick et al., 1993). Jones and Orr (1994) studied *in situ* toxin release by natural *M. aeruginosa* blooms treated with an organic copper-chelated algicide. In one instance, the concentration of extracellular microcystins increased from 4.7 µg/L to 1110 µg/L within 4 h post treatment. Subsequent analysis for the specific MCLR, showed similar results as non-detectable pre-treatment concentrations increased to 990 µg/L within 3 h post treatment. Microscopic examination of the cyanobacteria revealed few intact or otherwise healthy cells of *M. aeruginosa*. It is notable that in at least three historical accounts, human illness attributable to toxic cyanobacteria occurred following copper sulphate treatment of drinking water sources (i.e., Charleston, West Virginia – Tisdale, 1931; Palm Island, Queensland, Australia – Bourke et al., 1983; and Armidale, New South Wales, Australia – Falconer et al., 1983b).

In Alberta, nuisance blooms of cyanobacteria often contain microcystin. Of 380 phytoplankton biomass samples collected from 19 lakes between 1990 and 1992, more than 70% showed detectable levels (> 1 µg MCLR/g biomass dry weight) of MCLR (Hrudey et al., 1994). Toxin concentrations of phytoplankton samples from lakes and dugout ponds are highly variable. For instance, MCLR concentrations ranged from 4 to 605 µg/g dry weight in one study (Kotak et al., 1993), but exceeded 1500 µg/g in two others (Hrudey et al., 1994; Zurawell et al., 1999).

Research conducted over the past decade indicates that the inhabitants of several communities that are supplied with water derived from eutrophic sources risk ingesting low concentrations of microcystin from their daily drinking water intake, especially in summer and fall. Raw water samples collected over a 5-week period during autumn, 1992, from two Alberta drinking water sources (Driedmeat and Little Beaver lakes), contained mean microcystin concentrations ranging from 0.12 to 0.87 µg/L. Mean concentrations in treated water during this period ranged from 0.09 to 0.18 µg/L (Lambert et al., 1994). Similarly, microcystin concentrations in raw and treated water samples obtained from Little Beaver Lake during the period of July 20 to September 15, 1995, ranged from 0.1 to 0.5 µg/L and from non-detectable levels to 0.5 µg/L, respectively (Zurawell, unpublished). Few other lakes and reservoirs have been tested for microcystin. Consequently, information regarding the number of raw water supplies that support microcystin-producing cyanobacteria and the efficiency of drinking water treatment methods commonly employed in Alberta's municipalities is limited.

Concern regarding the human health effects attributable to cyanobacteria is global. The World Health Organization's Working Group on Protection and Control of Drinking-Water Quality previously identified cyanobacteria as an urgent area requiring attention. Federal and Provincial Governments of Canada have recognized the potential risks posed by naturally occurring microcystins and related toxins (Health Canada, 1998). As a result, potentially susceptible surface waters are now being monitored for microcystin in several provinces.

The goals of this research project were to determine, at a scoping level, the prevalence of microcystin in municipal drinking water sources and the adequacy of current water treatment in removing this toxin. Other cyanotoxins exist, but are not addressed in this study.

2.0 METHODS

2.1 Sampling

Eighteen communities and their raw water sources were selected for testing, based on two criteria: a confirmed history of dense cyanobacterial blooms during the summer months (as noted by water treatment plant operators); and on the commitment by the municipality to participate in the sampling program (Figure 1). As well, the municipalities were selected to include several different types of conventional and technologically-advanced treatment systems (Table 1).

To further study the efficacy of water treatment in removing microcy. in, samples were collected from various stages of a pilot-plant treatment facility involving a novel, fluidized bed bio-filter. This pilot-plant, located in the Village of Vilna, was adjacent to the conventional treatment facility and provided a convenient opportunity to compare the two processes. This pilot plant is part of a water treatment research project being undertaken by the Alberta Research Council.

Ten samples (one per week) were collected from each raw and treated water source between mid-August and mid-October. Raw water samples were collected near the drinking water intake and were obtained by filling a 500-mL plastic bottle approximately 30 cm beneath the surface. Final sample volume was adjusted to approximately 5 cm below the neck of the plastic bottle, by pouring out some sample, to allow for expansion when freezing. Samples were frozen immediately following collection to minimize natural toxin degradation.

Treated (finished) drinking water samples were collected from a tap located within the water treatment facility. The tap was opened and water was allowed to run for a minimum of three minutes. A 500-mL plastic bottle was filled to within approximately 5 cm below the bottle neck. Samples were frozen immediately.

Various stages of the pilot-plant (Figure 2) were sampled on three occasions (September 20th, 27th and October 3rd, 2001). Samples included the following phases: raw water; ozone contactor/dissolved gas floatation (DOF); fluidized bed bio-filter; sand filtration; granular activated carbon (GAC) treatment; and ultra violet light (UV) treatment. A sample of finished water resulting from the conventional treatment plant was also collected at this time.

Samples of raw water, conventionally treated water, and post bio-filtration water were also collected on October 12th and 18th.

2.2 Sample Analysis

All samples were analyzed for "total microcystin" concentration. Total microcystin includes dissolved extracellular and intracellular toxin; no attempt was made to differentiate between the two fractions. Samples were picked-up by HydroQual Laboratories Ltd. periodically throughout the study. The samples were thawed overnight. A 45-mL aliquot was removed after mixing of the sample. Aliquots were sonicated for 30 s to disrupt cyanobacterial cells. The treated water

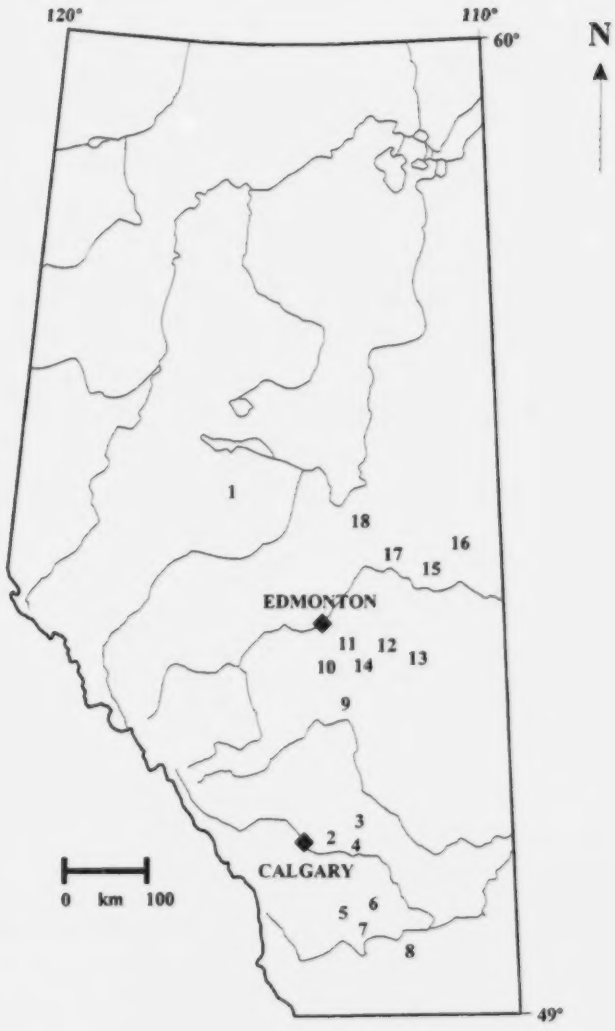

Figure 1 Map of Alberta, Canada showing geographic locations of the 18 study sites

(1) Town of Swan Hills; (2) Town of Strathmore; (3) Village of Rockyford; (4) Town of Gleichen; (5) Village of Carmangay; (6) Village of Lomond; (7) Town of Picture Butte; (8) Town of Taber; (9) Village of Mirror; (10) City of Wetaskiwin; (11) Village of Hay Lakes; (12) Village of Holden; (13) Town of Viking; (14) City of Camrose; (15) Town of St. Paul; (16) Town of Bonnyville; (17) Village of Vilna; and (18) Village of Boyle.

Table 1 List of study sites, their raw water sources and water treatment technology

Site #	Municipality	Raw Water Source	Water Treatment Technology
1	Town of Swan Hills	Freeman Lake	Conventional
2	Town of Strathmore	Reservoir [a]	Conventional
3	Village of Rockyford	Reservoir [a]	Conventional
4	Town of Gleichen	Reservoir [a]	Conventional
5	Village of Carmangay	Reservoir [b]	Conventional
6	Village of Lomond	Reservoir [c]	Conventional
7	Town of Picture Butte	Butte Lake [d]	Membrane Filtration
8	Town of Taber	Reservoir [e]	Conventional
9	Village of Mirror	Creek	Conventional
10	City of Wetaskiwin	Coal Lake	Conventional
11	Village of Hay Lakes	Reservoir	Conventional
12	Village of Holden	Reservoir	Conventional
13	Town of Viking	Iron Creek	Conventional
14	City of Camrose	Driedmeat Lake	PAC and UV Disinfection
15	Town of St. Paul	Lac St. Cyr [f]	Ozonation and GAC
16	Town of Bonnyville	Moose Lake	Conventional
17	Village of Vilna	Bonnie Lake	Conventional
18	Village of Boyle	Skeleton Lake	Conventional

Notes:
[a] Diverted from Western Irrigation canal system (Bow River).
[b] Diverted from Little Bow River.
[c] Diverted from Bow River Irrigation District canal system (Bow River).
[d] Diverted from Oldman River.
[e] Drawn from Chin Lake (St. Mary's River Irrigation District canal system).
[f] Diverted from North Saskatchewan River during winter months.
Conventional treatment processes typically include coagulation, flocculation (ferric chloride or aluminum sulphate), sedimentation, sand filtration and chlorination.
Membrane filtration follows coagulation, flocculation and precedes chlorine disinfection.
PAC (powdered activated carbon) treatment for the removal of organic compounds.
GAC (granular activated carbon) treatment for the removal of organic compounds.
Ozonation involves using ozone contactors at multiple stage of the water treatment process.

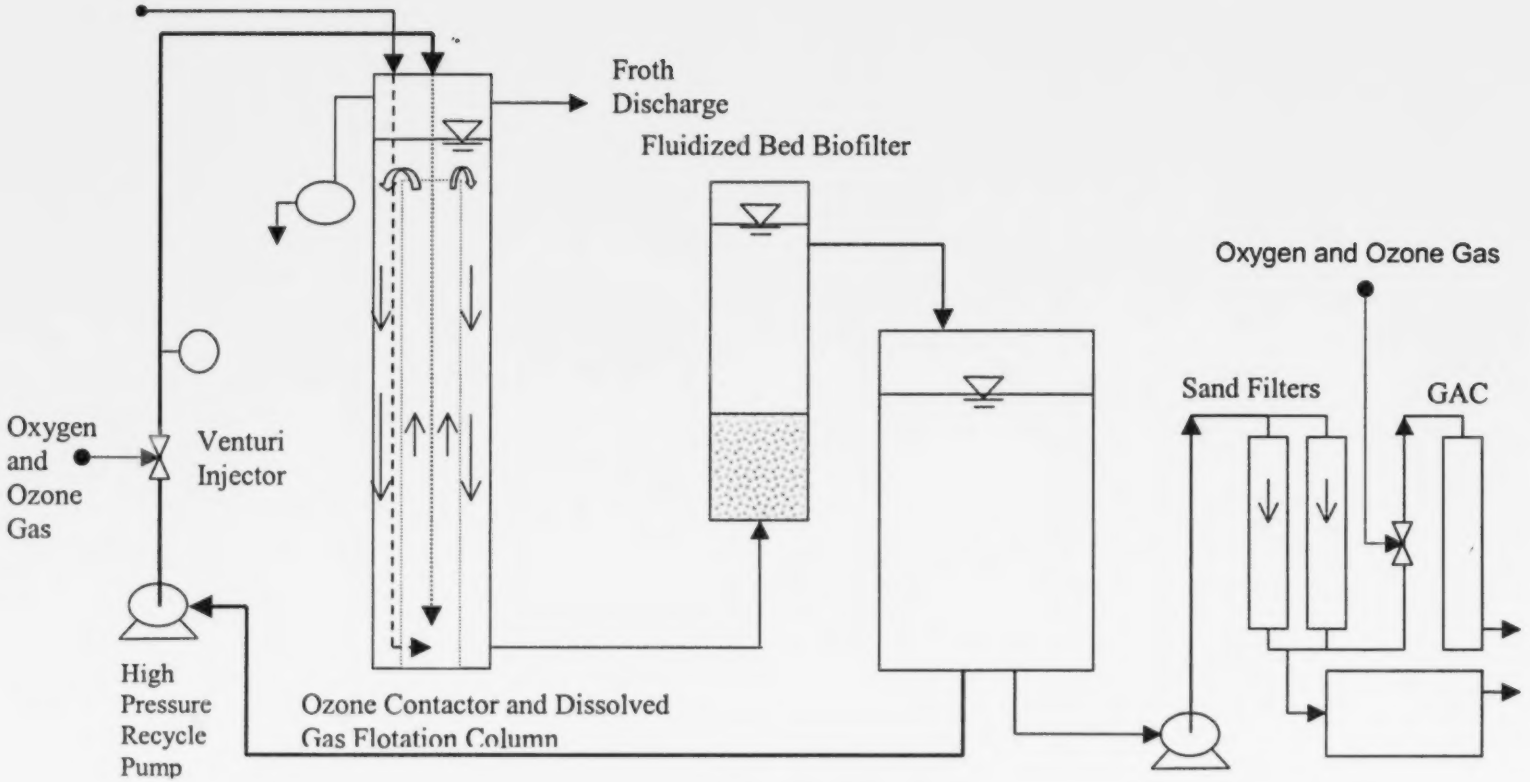

Figure 2 Bio-filter pilot facility flow schematic

GAC – granular activated carbon contactor; P – pressure guage; PRV – pressure release valve.
Courtesy of the Alberta Research Council, Water Treatment Technologies.

samples were processed in a similar manner as the raw water samples even though it was unlikely that they contained intact cells. Samples collected through the various stages of the bio-filter treatment train were also processed in this manner.

From the 45-mL sample aliquot, 1.8 mL was used in the protein phosphatase inhibition assay as specified by An and Carmichael (1994). The assay was chosen for this study over analytical (instrumental) methods, such as high performance liquid chromatography (HPLC), fast atom bombardment mass spectrometry (FABMS) and gas chromatography-mass spectrometry (GC-MS), because of its greater sensitivity to detect trace microcystin concentrations in finished drinking water.

Previous research indicates that multiple microcystin analogues exist in several of the raw water sources included in this study. Current analytical methods can discriminate between some individual microcystin analogues, but few toxin standards necessary for quantitative analyses are available commercially. The PP1 inhibition assay is based on the actual mode of microcystin toxicity, that is, the irreversible binding and subsequent inhibition of protein phosphatase type 1 and 2A (PP1 and PP2A). It quantifies all unbound (i.e., toxin fractions not bound to PP1 or PP2A), bioactive (i.e., microcystins capable of inhibiting PP1) toxin analogues, though differentiation between and identification of various analogues is not possible. Microcystin concentrations were extrapolated from curves plotting PP1 inhibition by microcystin-LR standards (Sigma-Aldrich Canada Ltd., Oakville, ON, Canada) and are thus expressed as "µg MCLR equivalents/L". Hence, microcystin concentrations presented in this report as "µg MCLR equivalents/L" are a measure of all bioactive microcystin analogues or "total microcystin"

3.0 RESULTS AND DISCUSSION

3.1 Microcystin in Raw Water

The eighteen municipalities chosen for this study (Table 1) varied with respect to population size (i.e., potential water demand), sophistication of drinking water treatment methodology and ultimate source of raw water (i.e., direct from natural lakes, reservoirs filled from natural lakes or from rivers via irrigation canal systems). These communities reside within four distinct eco-regions of the province (Figure 1): north-west boreal region (municipality 1); east boreal-mixed wood region (municipalities 15, 16, 17 and 18); east-central aspen parkland region (municipalities 9, 10, 11, 12, 13 and 14); and the southern prairie-grassland region (municipalities 2, 3, 4, 5, 6, 7, and 8).

Of the surface water samples collected over the 10-week period, 67% contained detectable concentrations of microcystin (Table A1). However, during the first 5 weeks of study (all sampling dates up to September 15th), 83% of raw water samples contained microcystin. This coincides with a time of year when water temperatures are warmest and when cyanobacteria are most likely to be present.

Microcystin was detected at least once in all raw water sources with the exception of Freeman Lake, where it was never detected (Table A3). Freeman Lake is the water supply for the Town of Swan Hills (Table 1). Ten raw water sources (see Tables A4, A5, A7, A8, A9, A10, A11, A14, A15 and A17) contained low toxin concentrations (i.e., ≤ 0.5 µg MCLR eq./L), while moderate concentrations (i.e., 0.5 – 14.8 µg MCLR eq./L) were detected in the remaining seven (Tables A6, A12, A13, A16, A18, A19 and A20).

Regional differences with respect to microcystin concentrations in raw water sources are evidenced by the fact that higher toxin concentrations were prevalent in waters located within the east boreal-mixed wood and east-central aspen parkland regions. There are several potential explanations for this observation.

- In the east boreal-mixed wood and east-central aspen parkland regions, communities often derive drinking water directly from eutrophic lakes or storage reservoirs (Table 1) in which toxin-producing cyanobacteria (i.e., *Microcystis*, *Anabaena* and *Nostoc*) often dominate the phytoplankton communities. In contrast, south prairie-grassland communities rely primarily on irrigation canals. Within such relatively unproductive, flowing waters cyanobacteria are relatively uncommon.

- The time period (mid-August to mid-October) in which the study was conducted may also explain the lower concentrations detected in raw waters located within the southern region. Generally, southern Alberta's surface waters warm more quickly and to higher temperatures than more northern waters. As a result, phytoplankton community succession within these warmer waters can progress in such a manner that cyanobacteria come to dominate earlier during the summer months (i.e., June – July). It is possible that raw waters located in the southern region contained few

cyanobacteria (or non-toxic species) during this period as populations inevitably decline following earlier peaks in abundance and biomass. If the study had been conducted from early to mid-summer, results may have been different.

3.2 Microcystin in Treated Water

Health Canada has recently adopted1.5 µg/L as a guideline for total microcystin in drinking water. The risk to human health generated by the consumption of treated water originating from Alberta's eutrophic lakes and reservoirs can be evaluated by compliance assessment with this guideline.

Microcystin was detected in the treated water of five municipalities: Picture Butte, Wetaskiwin, Viking, Bonnyville, and Vilna (Table A2); these incidences usually coincided with elevated toxin concentrations in the raw water. Compared to raw water, however, microcystin was detected considerably less frequently (10% of all treated water samples compared to 67% of all raw water samples) and at lower concentrations (treated water ≤ 0.50 µg MCLR eq./L compared to up to 14.8 µg MCLR eq./L in source water). In all instances, toxin concentrations in treated water complied with the Health Canada guideline value.

These results are comparable to those reported previously for treated water derived from two eutrophic Alberta lakes (Lambert et al., 1994; Zurawell, unpublished). Similar findings were also reported following a two-year rural water quality study conducted by Manitoba Environment during 1995-96 (< 0.1-1.0 µg/L and <0.1-0.6 µg/L detected in raw and treated water samples, respectively; Jones, 1996). A recent survey of selected municipalities in the USA and Canada indicated that the majority of raw water supplies tested contained microcystin, but that almost all utilities had adequate procedures to reduce microcystins to safe levels in the finished water (Carmichael 2001).

The majority of municipalities in this study utilize conventional means for drinking water treatment (Table 1). Of these, ten communities used treatment systems that consistently reduce microcystin levels to concentrations lower than the analytical detection limit (i.e., <0.07µg MCLR eq./L) (i.e., Towns of Strathmore, Gleichen and Taber and the Villages of Rockyford, Carmangay, Lomond, Mirror, Hay Lakes, Holden and Boyle). Although the Towns of Viking and Bonnyville, the Village of Vilna and the City of Wetaskiwin often achieved microcystin concentration reductions below the analytical detection limit, some samples still contained detectable, but low levels of the toxin. This suggests that conventional water treatment practices can remove some (but not all) toxin from contaminated source waters. It is worth noting that even when concentrations are reported as "less than the analytical detection limit" very low levels of microcystin may be present, but go undetected because of analytical limitations.

Several municipalities employ more sophisticated processes including: powdered activated carbon (PAC) and UV disinfection (City of Camrose); granular activated carbon (GAC) and ozonation (Town of St. Paul); and membrane filtration (Town of Picture Butte). Microcystin was not detected in treated water samples from Camrose or St. Paul, but 50% of the treated water

samples from Picture Butte had low, detectable concentrations. Although it is difficult to assess drinking water treatment efficacy due to the variability in source water toxin concentrations, several comparisons are noteworthy. For instance, the highest raw water toxin concentrations observed were from the cities of Wetaskiwin and Camrose (sources: Coal Lake and Driedmeat Lake, respectively; Tables A12 and A16). While the City of Wetaskiwin utilizes conventional treatment, more sophisticated treatment involving PAC addition and UV disinfection is employed by the City of Camrose. Previous laboratory and pilot studies indicate that the use of PAC (toxin adsorption; Falconer et al., 1983a) and/or UV disinfection (photolytic toxin degradation; Robertson et al., 1998), along with traditional methods, can remove a larger portion of microcystin from water. As a result, microcystin was often detected in drinking water obtained from the City of Wetaskiwin, but was never found in drinking water from the City of Camrose.

Microcystin was not detected in finished water from the Town of St. Paul, which utilizes ozone treatment (ozone catalyzes the rapid destruction of microcystin; Rositano et al., 1998) in concert with GAC. In this case, toxin levels in the source water were low ($\leq$ 0.12 µg MCLR eq./L; Table A17), hence comparison of the efficacy of this treatment method with others may not be appropriate. Relevant to this study, though, are the results of previous full-scale water treatment trials in Camrose and Ferintosh, Alberta, that demonstrated conventional processes combined with activated carbon (either PAC or GAC) generally removed more than 80% of initial microcystin content from raw water (Lambert et al., 1996).

In contrast, toxins were detected on several occasions in finished water from the Town of Picture Butte. The Town employs membrane filtration technology instead of dual media or GAC filtration following coagulation and flocculation. This is notable, as microcystin concentrations in the source water were relatively low ($\leq$ 0.14 µg MCLR eq./L; Table A9). Membrane filtration should effectively remove cyanobacterial colonies, though results presented here suggest that dissolved toxins were not removed.

3.3 Fluidized Bed Bio-Filter Assessment

The final aspect of this project was to assess microcystin concentrations at various stages of a pilot-scale water treatment train incorporating a fluidized bed bio-filter process. The pilot treatment processes were housed in a trailer immediately adjacent to the conventional water treatment facility located within the Village of Vilna (see Figure 2 for a schematic representation; Appendix B for process description).

Sequential stages of the pilot-plant were sampled during three weeks of the study (raw intake water and post-fluidized bed samples were collected for five weeks). Generally, microcystin was detected in raw water and all stages of the pilot-scale water treatment plant during much of the sampling period. Raw water toxin concentrations were moderate during the first three weeks (0.39-1.0 µg MCLR eq./L), and declined to low levels during the final two weeks (Table A21). In all cases, toxin concentrations immediately following the fluidized bed bio-filter showed a variable degree of reduction compared to raw water. Also, microcystin in water subject to GAC filtration were generally lower than in water with UV treatment.

Conventional treatment at Vilna also yielded variable reductions in microcystin levels during the five-week period (Table A21). This contrasts with the longer-term results for Vilna (Table A19) and suggests that more detailed or frequent sampling may be needed to depict microcystin levels.

Overall, the results are somewhat inconclusive, but suggest an apparent improvement in bio-filtration efficiency and a decline in conventional treatment efficiency with declining (or low) influent microcystin concentrations. These interpretations should be considered preliminary; research is continuing through 2002.

Many factors can affect water treatment efficiency. Foremost to be considered is the proportion of microcystin contributed by intracellular versus extracellular fractions. Mechanisms for effective removal of intracellular toxin from influent water (i.e., isolation of intact cyanobacteria by floatation or filtration), differ from those required for extracellular toxin (i.e., microcystin absorption via GAC or PAC and oxidation via ozonation or UV treatment). Pre-treatment methods relying on oxidative degradation (such as ozone treatment) can result in cyanobacterial cell lysis and a subsequent increase in dissolved, extracellular toxin concentration. Though no attempt was made to differentiate between the toxin fractions in raw water, it is possible that a proportionately greater concentration of intracellular toxin existed in samples collected during the first three weeks of the bio-filter study. The lysis of cells caused by ozone pre-treatment could explain the elevated microcystin levels observed during this period, compared to the conventional process which lacks ozone pre-treatment.

4.0 CONCLUSIONS

The objectives were to determine the prevalence of microcystin in municipal drinking water sources and whether current water treatment practices are adequate in removing these toxins. Our results indicate that low to moderate concentrations of microcystin are common in the majority (67%) of raw water samples collected during the study and that the toxin remains detectable beyond the warm water season and throughout autumn. This is a significant finding as past research regarding cyanobacterial toxins has focused primarily on warm summer months (it is a common misconception that toxic cyanobacterial blooms only occur during calm, hot summer days).

In contrast to source water, microcystin appeared less often (10%) and at lower concentrations in treated water. These results indicate that conventional water treatment practices remove some toxin from contaminated source waters. Municipalities employing additional and sophisticated water treatment technologies (e.g., PAC, GAC, UV and ozonation) appear to remove more microcystin than those relying on conventional methods only. Some technology, such as membrane filtration, may be unsuitable or otherwise ineffective at removing toxins. Nevertheless, toxin concentrations in treated drinking water never exceeded the guideline (1.5 µg/L) recently adopted by Health Canada (Health Canada, 1998).

Further monitoring should be conducted on raw waters that develop cyanobacteria blooms and municipal drinking water produced from such sources. Inclusion of winter samples may be warranted because toxic *Microcystis* colonies congregate on sediments during winter months. Relatively few communities were included in this study. In order to gain further insight to the prevalence of microcystin in treated water, it is suggested that a broader range of communities be assessed.

The discrepancy in results between weekly sampling and more frequent sampling from the Vilna treated water indicates that weekly sampling can miss the occurrence of microtoxin in water and suggests that more frequent sampling is needed.

Beyond the aforementioned recommendations, further research is needed with respect to reservoir management, treatment efficacy and detailed aspects of the occurrence and distribution of the toxins (e.g., there is a need to determine the fate of toxic cyanobacterial cells/colonies in the drinking water treatment process; resolve pathways of microcystin reduction by various drinking water treatment processes; determine the relative importance of microcystin fractions [dissolved extracellular and intracellular toxins]; determine toxin analogues responsible for toxicity; survey for the presence of other cyanobacterial toxins (i.e., anatoxins and saxitoxins); and extend the surveys to early summer months, particularly in southern Alberta).

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APPENDICES

Appendix A Data summaries for communities included in the microcystin study

Table A1 Data summary of Microcystin in raw water

Site #	Municipality	Number of Samples	Mean Microcystin Concentration (µg MCLR eq./L)	Range in Microcystin Concentration (µg MCLR eq./L)
1	Town of Swan Hills	6	<0.07	<0.07
2	Town of Strathmore	7	0.08	<0.07 – 0.20
3	Village of Rockyford	10	<0.07	<0.07 – 0.13
4	Town of Gleichen	5	0.48	<0.07 – 1.8
5	Village of Carmangay	10	<0.07	<0.07 – 0.13
6	Village of Lomond	10	<0.07	<0.07 – 0.10
7	Town of Picture Butte	10	0.11	0.09 – 0.14
8	Town of Taber	10	0.11	<0.07 – 0.47
9	Village of Mirror	10	<0.07	<0.07 – 0.08
10	City of Wetaskiwin	10	5.04	0.09 – 14.8
11	Village of Hay Lakes	10	0.24	<0.07 – 1.5
12	Village of Holden	10	0.20	0.07 – 0.45
13	Town of Viking	10	0.07	<0.07 – 0.23
14	City of Camrose	10	1.52	0.14 – 3.5
15	Town of St. Paul	10	<0.07	<0.07 – 0.12
16	Town of Bonnyville	10	0.66	0.10 – 1.1
17	Village of Vilna	10	0.01	0.21 – 2.3
18	Village of Boyle	10	0.24	<0.07 – 0.60

Table A2 Data summary of microcystin in treated water

Site #	Municipality	Number of Samples	Mean Microcystin Concentration (µg MCLR eq./L)	Range in Microcystin Concentration (µg MCLR eq./L)
1	Town of Swan Hills	6	<0.07	<0.07
2	Town of Strathmore	7	<0.07	<0.07
3	Village of Rockyford	10	<0.07	<0.07
4	Town of Gleichen	5	<0.07	<0.07
5	Village of Carmangay	10	<0.07	<0.07
6	Village of Lomond	10	<0.07	<0.07
7	Town of Picture Butte	10	<0.07	<0.07 – 0.12
8	Town of Taber	10	<0.07	<0.07
9	Village of Mirror	10	<0.07	<0.07
10	City of Wetaskiwin	10	0.13	<0.07 – 0.5
11	Village of Hay Lakes	10	<0.07	<0.07
12	Village of Holden	10	<0.07	<0.07
13	Town of Viking	10	<0.07	<0.07 – 0.08
14	City of Camrose	10	<0.07	<0.07
15	Town of St. Paul	10	<0.07	<0.07
16	Town of Bonnyville	10	<0.07	<0.07 – 0.08
17	Village of Vilna	10	<0.07	<0.07 – 0.09
18	Village of Boyle	10	<0.07	<0.07

Table A3 Town of Swan Hills data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/24/2001	<0.07	<0.07
8/30/2001	<0.07	<0.07
9/6/2001	<0.07	<0.07
9/17/2001	<0.07	<0.07
9/20/2001	<0.07	<0.07
9/27/2001	<0.07	<0.07

Table A4 Town of Strathmore data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	0.10	<0.07
8/27/2001	0.07	<0.07
9/2/2001	0.20	<0.07
9/7/2001	0.08	<0.07
9/11/2001	0.08	<0.07
9/17/2001	<0.07	<0.07
9/24/2001	<0.07	<0.07

Table A5 Village of Rockyford data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
9/9/2001	0.07	<0.07
9/17/2001	0.10	<0.07
9/24/2001	0.09	<0.07
9/30/2001	0.13	<0.07
10/7/2001	<0.07	<0.07
10/14/2001	<0.07	<0.07
10/21/2001	<0.07	<0.07
10/28/2001	<0.07	<0.07
11/4/2001	<0.07	<0.07
11/11/2001	<0.07	<0.07

Table A6 Town of Gleichen data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.24	<0.07
8/24/2001	0.14	<0.07
9/7/2001	1.8	<0.07
9/24/2001	0.19	<0.07
10/1/2001	<0.07	<0.07

Table A7 Village of Carmangay data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.08	<0.07
8/22/2001	0.10	<0.07
8/29/2001	0.13	<0.07
9/5/2001	0.10	<0.07
9/12/2001	0.08	<0.07
9/19/2001	<0.07	<0.07
9/26/2001	<0.07	<0.07
10/3/2001	<0.07	<0.07
10/10/2001	<0.07	<0.07
10/17/2001	<0.07	<0.07

Table A8 Village of Lomond data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/18/2001	0.09	<0.07
8/24/2001	0.07	<0.07
8/31/2001	<0.07	<0.07
9/7/2001	0.10	<0.07
9/14/2001	0.09	<0.07
9/22/2001	<0.07	<0.07
9/28/2001	<0.07	<0.07
10/5/2001	<0.07	<0.07
10/12/2001	<0.07	<0.07
10/19/2001	<0.07	<0.07

Table A9 Town of Picture Butte data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.09	<0.07
8/24/2001	0.14	<0.07
8/31/2001	0.10	0.07
9/7/2001	0.10	0.12
9/14/2001	0.12	<0.07
9/21/2001	0.09	<0.07
9/28/2001	0.10	<0.07
10/4/2001	0.09	0.08
10/11/2001	0.10	0.07
10/19/2001	0.12	0.08

Table A10 Town of Taber data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.10	<0.07
8/22/2001	0.13	<0.07
8/29/2001	0.12	<0.07
9/5/2001	0.09	<0.07
9/12/2001	0.47	<0.07
9/19/2001	<0.07	<0.07
9/26/2001	0.13	<0.07
10/3/2001	<0.07	<0.07
10/10/2001	<0.07	<0.07
10/17/2001	<0.07	<0.07

Table A11 Village of Mirror data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	<0.07	<0.07
8/24/2001	<0.07	<0.07
8/30/2001	<0.07	<0.07
9/7/2001	0.08	<0.07
9/14/2001	<0.07	<0.07
9/22/2001	<0.07	<0.07
9/28/2001	<0.07	<0.07
10/7/2001	<0.07	<0.07
10/12/2001	<0.07	<0.07
10/19/2001	<0.07	<0.07

Table A12 City of Wetaskiwin data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	12.5	0.50
8/24/2001	14.8	0.25
8/30/2001	7.79	0.15
9/6/2001	11.8	0.20
9/14/2001	0.10	0.10
9/20/2001	1.2	<0.07
9/28/2001	1.7	0.07
10/5/2001	0.23	<0.07
10/12/2001	0.14	<0.07
10/19/2001	0.09	<0.07

Table A13 Village of Hay Lakes data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.11	<0.07
8/20/2001	1.5	<0.07
8/27/2001	0.44	<0.07
9/4/2001	0.11	<0.07
9/10/2001	0.15	<0.07
9/17/2001	0.08	<0.07
9/24/2001	<0.07	<0.07
10/1/2001	<0.07	<0.07
10/8/2001	<0.07	<0.07
10/15/2001	<0.07	<0.07

Table A14 Village of Holden data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/17/2001	0.36	<0.07
8/24/2001	0.08	<0.07
8/31/2001	0.45	<0.07
9/7/2001	0.26	<0.07
9/13/2001	0.25	<0.07
9/21/2001	0.07	<0.07
9/28/2001	0.08	<0.07
10/5/2001	0.08	<0.07
10/12/2001	0.12	<0.07
10/19/2001	0.30	<0.07

Table A15 Town of Viking data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	0.07	<0.07
8/24/2001	<0.07	<0.07
8/31/2001	0.08	<0.07
9/7/2001	<0.07	<0.07
9/13/2001	0.07	<0.07
9/21/2001	<0.07	<0.07
9/28/2001	0.08	0.08
10/5/2001	0.23	0.08
10/12/2001	0.15	<0.07
10/19/2001	<0.07	<0.07

Table A16 City of Camrose data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	1.7	<0.07
8/24/2001	2.0	<0.07
8/27/2001	3.5	<0.07
9/5/2001	2.4	<0.07
9/12/2001	1.3	<0.07
9/19/2001	1.8	<0.07
9/24/2001	1.6	<0.07
10/5/2001	0.89	<0.07
10/12/2001	0.14	<0.07
10/19/2001	0.28	<0.07

Table A17 Town of St. Paul data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	<0.07	<0.07
8/24/2001	0.12	<0.07
8/31/2001	<0.07	<0.07
9/7/2001	<0.07	<0.07
9/14/2001	<0.07	<0.07
9/21/2001	<0.07	<0.07
9/28/2001	0.08	<0.07
10/5/2001	<0.07	<0.07
10/12/2001	0.10	<0.07
10/19/2001	<0.07	<0.07

Table A18 Town of Bonnyville data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/23/2001	0.53	<0.07
8/31/2001	0.93	<0.07
9/1/2001	0.85	<0.07
9/8/2001	1.1	0.07
9/16/2001	1.1	<0.07
9/23/2001	0.69	0.08
9/30/2001	0.49	<0.07
10/7/2001	0.10	<0.07
10/14/2001	0.64	<0.07
10/21/2001	0.12	<0.07

Table A19 Village of Vilna data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	0.94	<0.07
8/24/2001	0.80	<0.07
8/27/2001	1.3	<0.07
9/3/2001	2.3	0.09
9/10/2001	2.0	<0.07
9/17/2001	0.51	<0.07
9/28/2001	0.39	<0.07
10/1/2001	1.1	<0.07
10/16/2001	0.63	<0.07
10/25/2001	0.21	<0.07

Table A20 Village of Boyle data summary

Sampling Date	Microcystin Concentration Raw Water (µg MCLR eq./L)	Microcystin Concentration Treated Water (µg MCLR eq./L)
8/20/2001	0.60	<0.07
8/24/2001	0.48	<0.07
8/29/2001	0.24	<0.07
9/5/2001	0.26	<0.07
9/13/2001	0.21	<0.07
9/19/2001	0.36	<0.07
9/26/2001	<0.07	<0.07
10/3/2001	0.15	<0.07
10/11/2001	<0.07	<0.07
10/17/2001	0.14	<0.07

Table A21 Biological filter pilot-plant data summary

Treatment Stage	Microcystin Concentration (µg MCLR eq./L)				
	Collected 9/20/2001	Collected 9/27/2001	Collected 10/03/2001	Collected 10/12/2001	Collected 10/18/2001
Raw Water	0.41	0.39	1.0	0.19	0.09
Post OC/DOF Treatment	0.67	0.24	0.11		
Post Bio-filtration	0.22	0.07	0.58	0.09	<0.07
Post Sand Filtration	0.35	0.14	0.55		
Post GAC Treatment	0.30	0.24	0.31		
Post UV Treatment	0.44	0.41	0.15		
Conventional Treatment	<0.07	0.08	0.12	0.09	0.1

Appendix B Bio-filter pilot plant process description*

A variable speed progressive cavity pump was used to control the inlet flow from the raw water reservoir. This supply was directed to the bottom of the inside tube of the flotation column, where it joined with the ozonated recycle flow. The combined streams overflowed into the outer annulus that served as a counter-current clarification zone in the flotation system. A pressure relief valve was attached to the top, froth-collection part of the column. Froth was removed at timed intervals either by opening a solenoid valve or operating a peristaltic pump. Water from the bottom of the flotation column flowed upward through the fluidized sand biofilter and discharged into a stainless steel reservoir. The recycle flow was drawn from this reservoir by a high-pressure pump and passed through a venturi eductor before being directed to the bottom of the inside tube of the flotation column. Here the water pressure was released through a nozzle and the flow impinged on a plate near the point where the raw water was introduced. The eductor was used to inject oxygen and ozone into the high-pressure recycle loop to produce supersaturated flow. Downstream of the nozzle micro-bubbles were formed as gas was released from solution. Gas transfer and particle attachment occurred as water flowed upward through the inside tube; more particle attachment and floc growth took place as bubbles rose and expanded in the low-velocity, counter-current flow regime of the outer annulus. A separate pump and pressure tank were used to direct flow through the alternative treatment trains downstream of the reservoir. The flow passed first through two parallel sand pressure filters before splitting into two paths. Half the flow was directed via a venturi and contact column to a GAC contactor, the other half through a UV chamber.

* Courtesy of the Alberta Research Council, Water Treatment Technologies